Deployment Issues for Biodiesel: Fuel Quality and NO_x Emissions

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Non-Petroleum Based Fuels Activity
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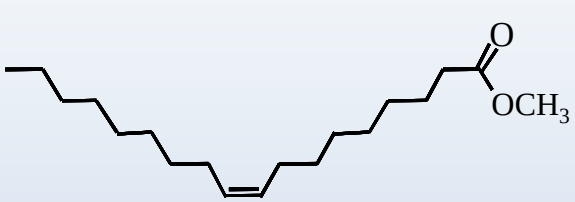
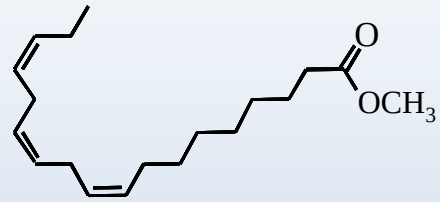
What is biodiesel?

- Mono-alkyl esters of fatty acids (i.e. methyl or ethyl esters)



oleic acid

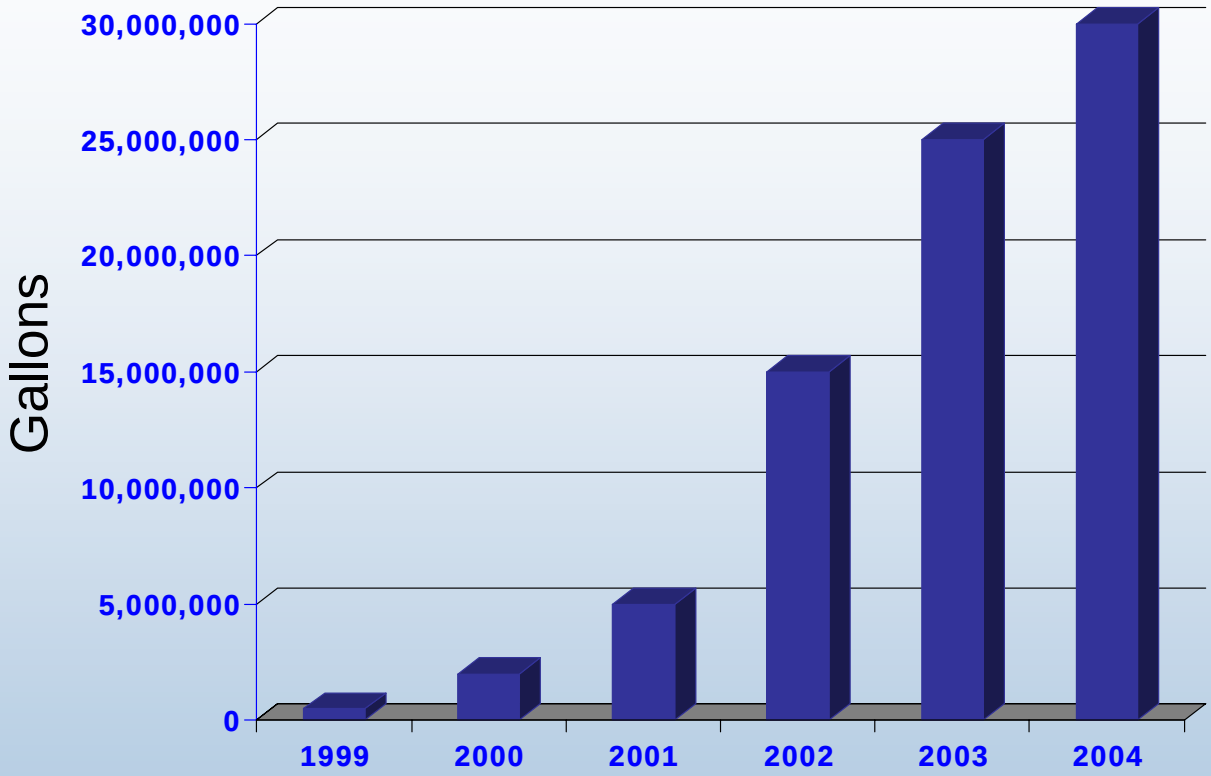
linoleic acid



linolenic acid

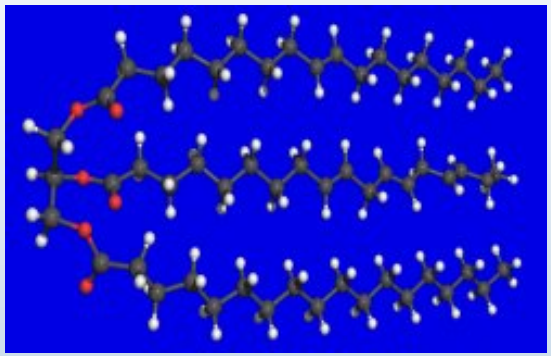
- Must meet the quality requirements of ASTM D6751
- Typically used as blend with petrodiesel (up to 20%)
- Current U.S. average rack price $3.30/gal (versus $1.86 for No. 2 diesel)
  - Prices are pre-tax and pre-tax credit

Biodiesel Production



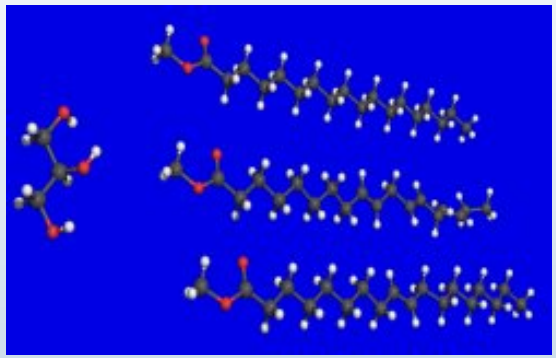
- *NBB estimates 75 million gallons in 2005*
- *Current production capacity is more than 290 million annual gallons*
- *More than 570 million annual gallons under construction or planned*

What is not biodiesel?



Fat or Oil Feedstock Triglyceride

Methanol
+
base
catalyst



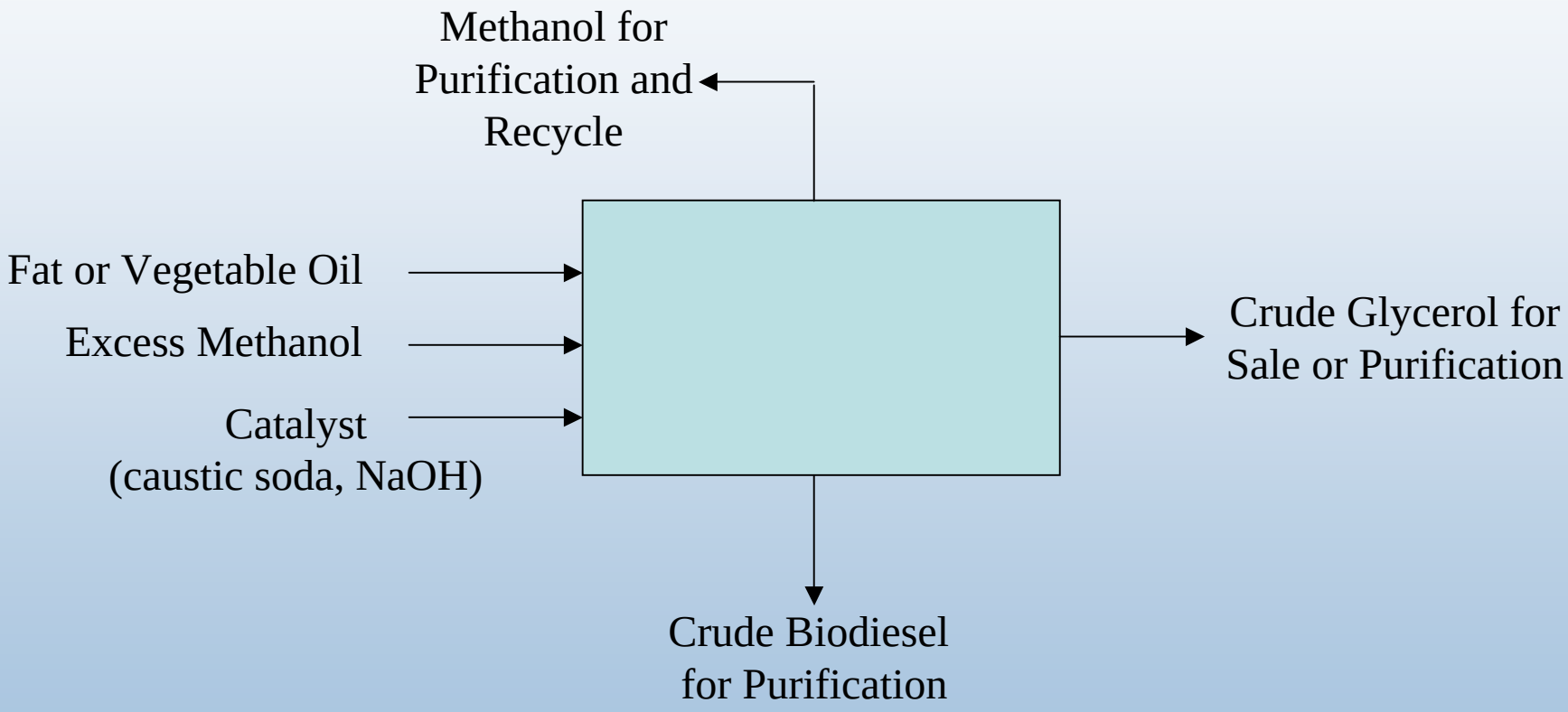
Glycerol Biodiesel Alkylesters

- Biodiesel is NOT unrefined vegetable oil or used cooking oil
- The much higher boiling point of straight vegetable oil leads to engine carbon deposits, reducing engine life or increasing maintenance costs

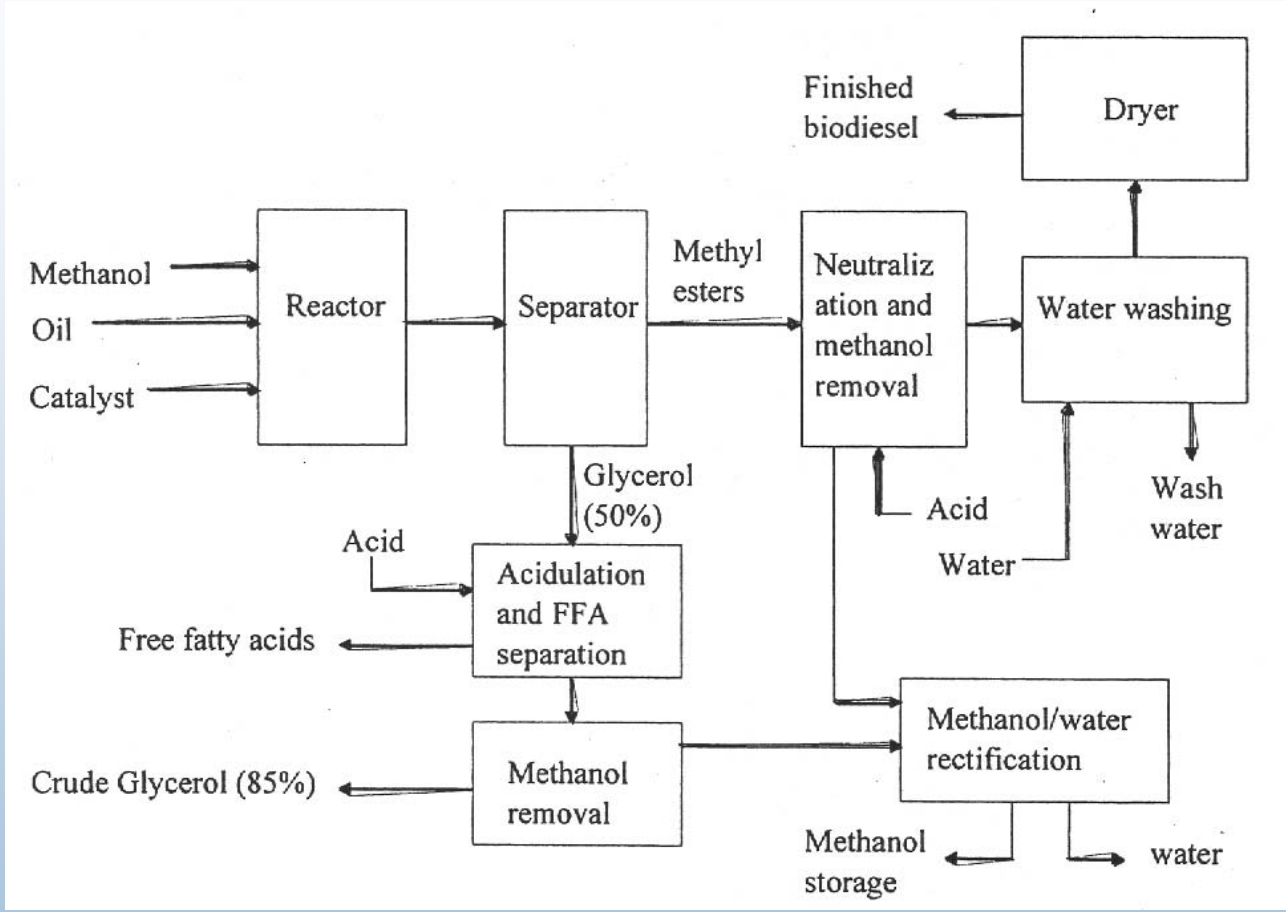
Making Biodiesel

			(Catalyst)			
100 pounds	+	10 pounds	=>	10 pounds	+	100 pounds
Triglyceride		Alcohol		Glycerin		Mono-Alkyl Esters
Soy oil		*Methanol*				*Biodiesel*

Biodiesel Production Process –Crude Products



Biodiesel Production Process - Details



Major opportunity for innovation and development of more advanced and efficient production processes

Potential Impurities in Biodiesel

- Methanol
  - Degrades some plastics and elastomers, corrosive
  - Can lower flashpoint to unsafe levels (fire safety)
- Unconverted/partly converted fat (bound glycerin)
  - Results in very poor cold flow properties, injector and in-cylinder deposits, potential engine failure
- Glycerin (free glycerin)
  - Results in injector deposits, clogged fuel filters, deposit at bottom of fuel storage tank
- Catalyst
  - Excessive injector, fuel pump, piston, and ring wear, filter plugging, issues with lubricant

ASTM D6751 Limits Impurities

- Flashpoint 130ºC minimum
  - Limits methanol to very low level
- Total glycerin is limited to 0.24 wt% maximum
- Free glycerin is limited to 0.02wt% maximum
- Sulfated ash is limited to 0.020 wt%
  - Limits catalyst and other impurities
  - D6751 being updated to limit Sodium + Potassium to 5 ppm max
- It is critical to insure that all B100 meets D6751 limits

"There is no place in the market for off-specification biodiesel" -Steve Howell, Technical Director, National Biodiesel Board

Quality Issues for Blends: B20 Quality Survey

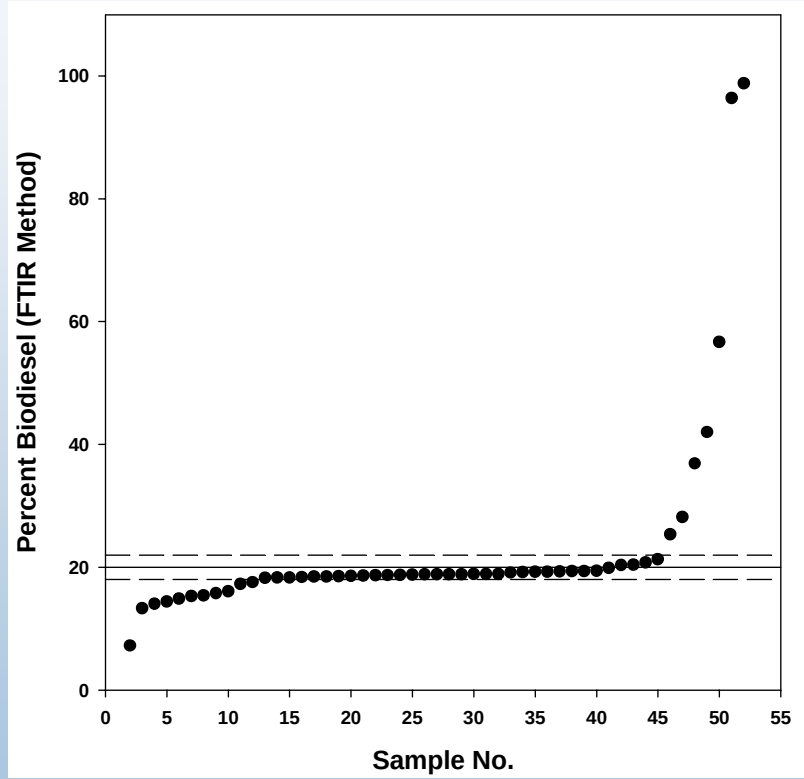
- Fifty samples collected nationwide
- All samples showed very low values for:
  - Water and sediment (D2709)
  - Haze rating (D4176)
  - Silver strip corrosion
- Other potential issues identified:
  - Low interfacial tension (water separator performance)
  - High peroxide value (oxidation instability of B100 or blend)
- About 32 samples actually tested as nominally 20% biodiesel

Poor Blending = Inconsistent Biodiesel Content

- 18 samples fall outside of 18-22% range

- Likely cause: <u>poor mixing during splash blending</u>
  - Need much higher flow rate, 300 gal/min or
  - Initiate mixing procedures
  - Switch to in-line blending

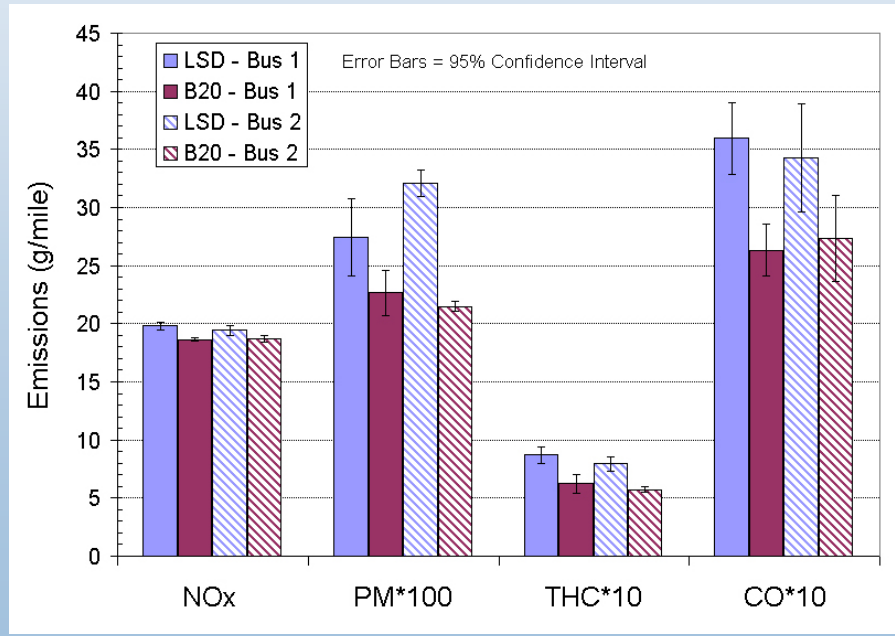
- Working with NBB to educate and inform blenders
  - Anecdotal evidence indicates this is still a problem



NO_x Emissions

Biodiesel Bus Chassis Dynamometer Testing

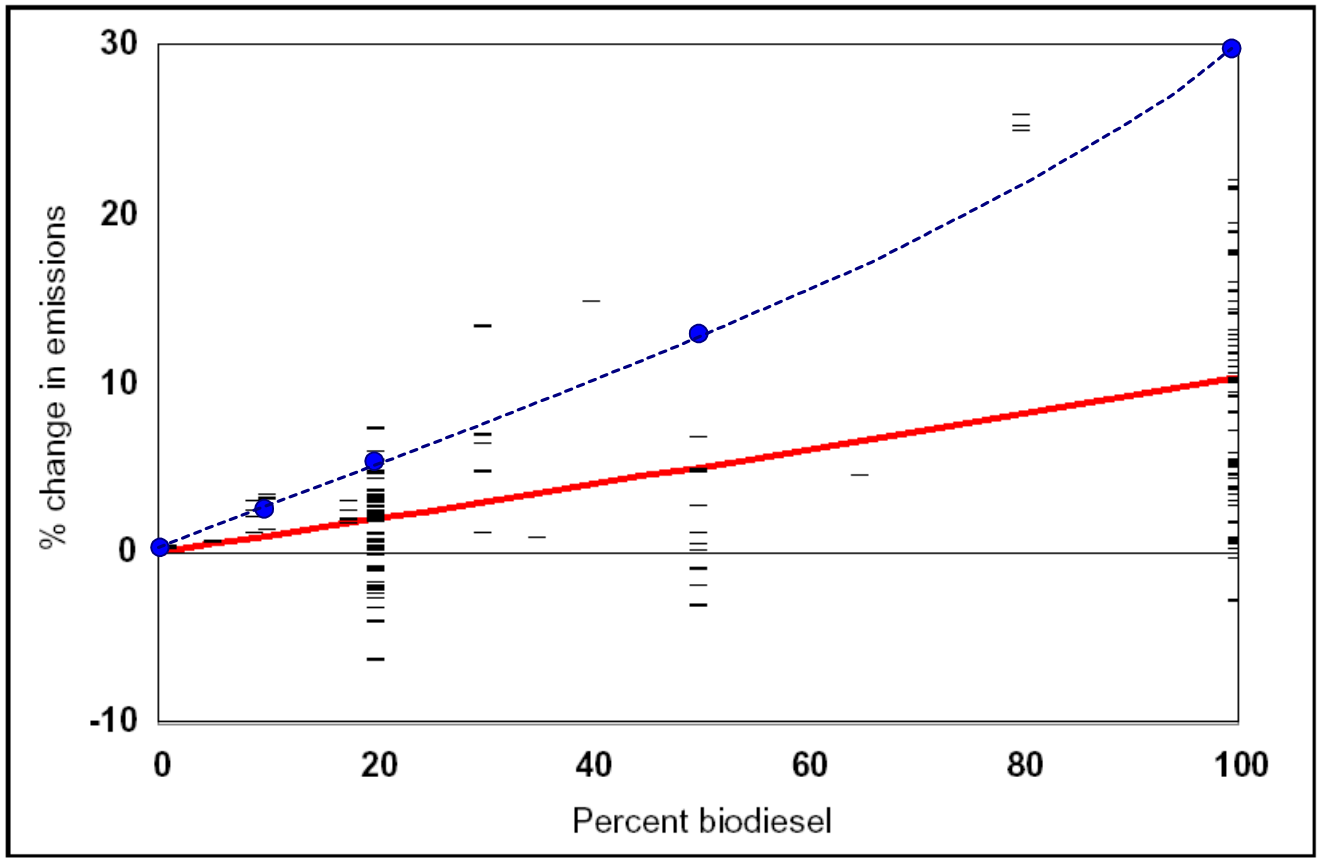
- B20 vs. conventional diesel fuel
- 3 in-use buses tested (40,000 lb GVWR)
- City Suburban Heavy Vehicle Cycle (CSHVC) at 35,000 lb inertia
- Cummins ISM 2000 Engine – No EGR
- Fuel economy reduction ≈ 3%
- Emission reductions (g/mile basis)
  - PM ≈ 18%
  - HC ≈ 29%
  - CO ≈ 24%
  - NO_x ≈ 4%
  - statistical confidence > 99%
- Entire study replicated in Feb and Sept 2005



Biodiesel's Effect on NO_x Emissions -Engine Data (conventional wisdom)

Typical Older Engines (thru 1997): **B20 = +2%, B100 = +10%**

Newer Engines (2004 compliant): **B20 = +4%, B100 = +30%**

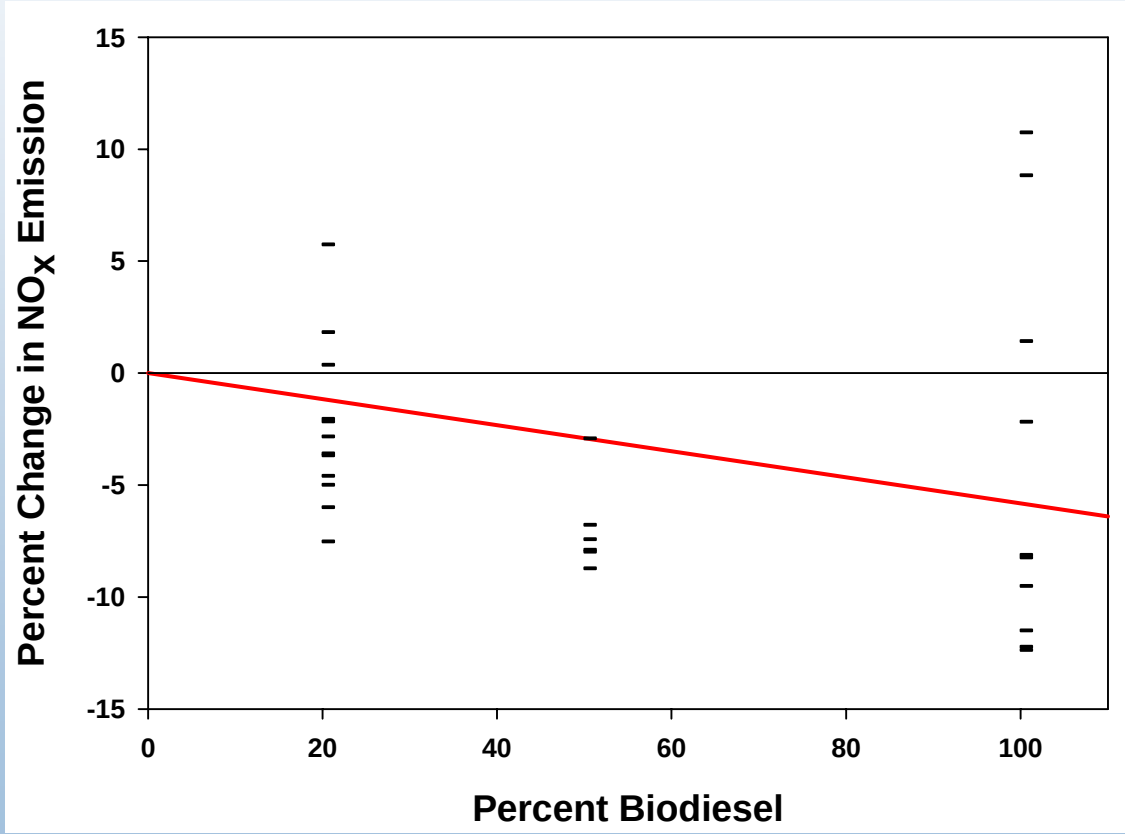


Analysis for Pre-1998 Engines from EPA420-P-02-001, Draft Report, October 2002

Analysis for newer engines, McCormick, et al., SAE Paper No. 2005-01-2200

Biodiesel's Effect on NO_x Emissions -Vehicle (Chassis) Data

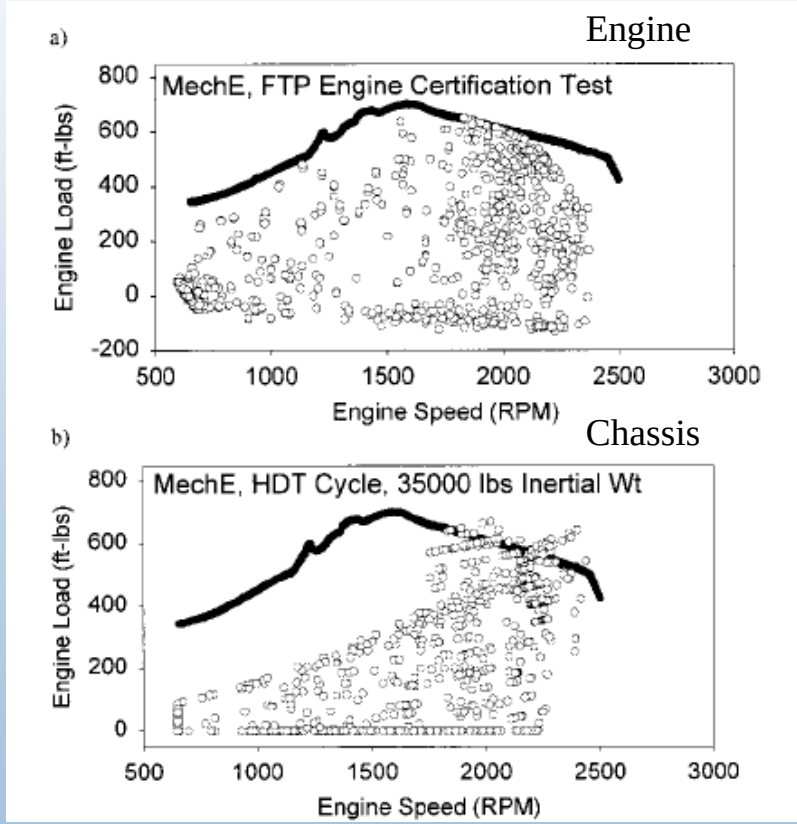
- *EPA study also reviewed published vehicle test data*
- *On average, NO_x was reduced in vehicle test studies*
  - *by 1.2% for B20*

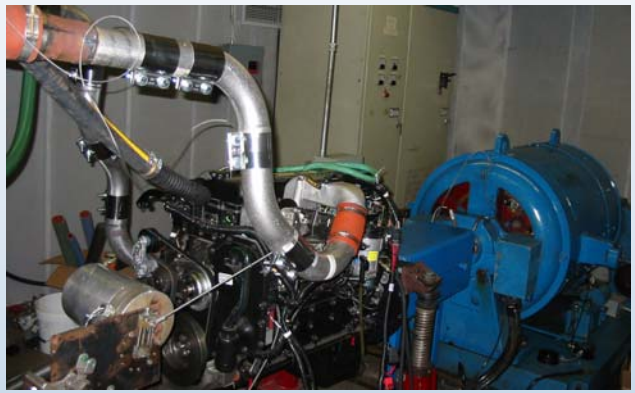


Data from EPA420-P-02-001, Draft Report, October 2002

Engine versus Chassis Test

Note difference in the speed and load points for the two different tests





Yanowitz, Graboski, and McCormick *Environ. Sci. Technol.* **2002**, 36, 270-275

Biodiesel Effect on NO_x Uncertainty

- *Engine tests on average show NO_x increasing*
  - *NO_x can go up or down depending on engine and test cycle - this is not well understood fundamentally*
  - *Finding of a NO_x increase is not based on testing of a representative sample of in-use engines*
  - *Finding of NO_x increase is not based on a market share weighted average*

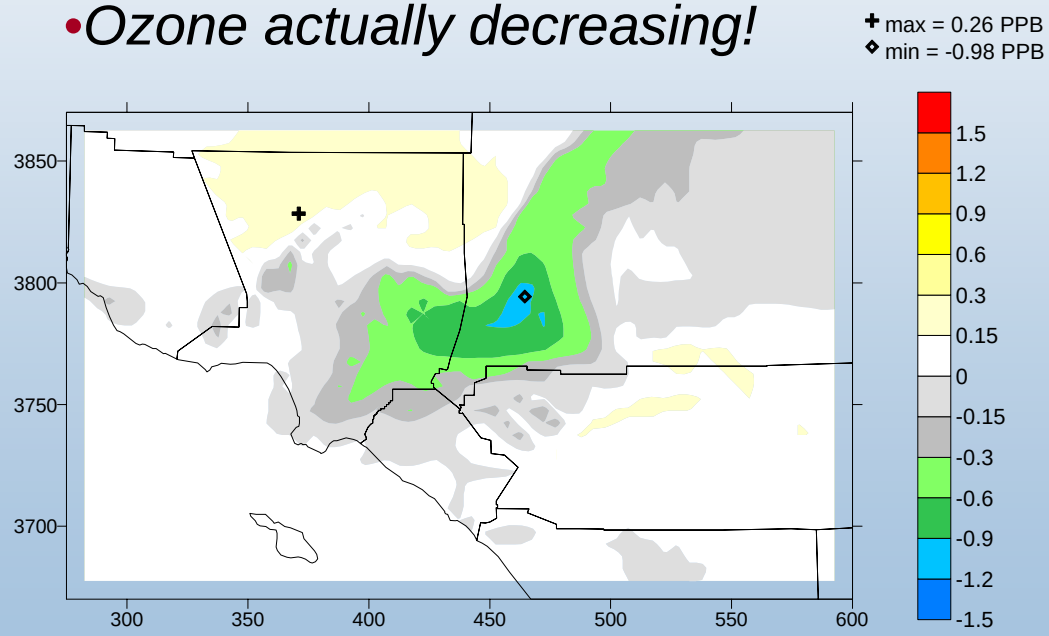
- *Vehicle tests on average show NO_x reductions*
  - *Very limited dataset*
  - *Again, not based on representative sample or market share weighted average*

Bottom Line on Biodiesel and NO_x

There are insufficient data, and insufficiently representative data, to draw any conclusions regarding the average effect of biodiesel blends on NOx emissions, even directionally

Air Quality Modeling for Biodiesel

- Impact of 100% market penetration of B20 on air quality in Chicago area, Northeast Corridor, and South Coast Air Basin.
- Air-shed scale effects –assuming 2% increase in NO_x:
  - *NO_x from B20 use has no negative air quality impact*
    - *Changes in ozone less than ~1 ppb*
    - *Ozone actually decreasing!*



Difference in Daily Max 1-Hour Ozone (ppb)
August 07, 1997
NREL Biodiesel -- 100% Penetration B20 Biodiesel minus Base

Analysis from NREL/SR-540-33793, April 2003

Weekday/Weekend Ozone Effect

- Ambient ozone levels are as high or higher on weekends than on weekdays in many urban U.S. locations, despite much lower emissions of the ozone precursors (hydrocarbons, carbon monoxide, and nitrogen oxides).

- Higher weekend ozone is caused by less titration of ozone by NO
  - lower NO emissions causes higher ozone
  - ongoing studies suggest all ozone non-attainment areas are HC limited

Conclusions validated in peer-reviewed publications July 2003

NO_x Summary

- Considerable uncertainty about the effect of biodiesel on NO_x emissions
  - Effects of engine, vehicle size, test cycle
- Assuming a 2% increase in NO_x emissions, impact on air quality is too small to measure
- Major study indicates NO_x is not the cause of high ambient ozone
- EPA is moving to a new *inventory model:*
  - Inventory models are used to predict future compliance with ambient air quality standards i.e. ozone (MOVES model)
  - Uses chassis and portable emissions monitor data – no engine dyno data – so will not penalize biodiesel
- Thus biodiesel (B20) provides:
  - *Energy security and greenhouse gas emissions benefits*
  - HC, toxic compound, and PM emissions reductions
  - No negative NO_x or ozone impact